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Upper air observations at the Seychelles, 1963–64

By P. B. WRIGHT, B.Sc. and R. A. EBDON

This memoir presents the upper air observations made in the Seychelles during the International Indian Ocean Expedition in 1963–64 at a radiosonde station which was set up and operated by the Meteorological Office.

The observations are discussed, and a comparison is made with similar observations from Gan.

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DIURNAL VARIATION OF THE INCIDENCE OF MONSOON RAINFALL OVER THE SUDAN (PART II)

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Summary. Using 15 years' data from 17 autographic rain-gauges in the Sudan, the diurnal variation of the incidence of monsoon rainfall has been tabulated by months. The considerable differences in space and time are systematic and reveal clearly defined patterns. These patterns are discussed in terms of the likely mechanisms for rainfall growth and suppression. Day-time convection, leading to a maximum incidence during the afternoon or early evening, is dominant only at places distant from the Ethiopian highlands. Elsewhere, rainfalls are more evenly distributed throughout the day, with weak maxima possible at any time, depending on location and month. However, an early morning maximum occurs widely. The Ethiopian highlands appear to influence the diurnal patterns in several ways and over distances of hundreds of kilometres.

Discussion. (Continued from Part I.[1])

Day-time convection. Growth of convective clouds is favoured not only by instability but also by a moist environment, because mixing of the cloud with a dry environment results in evaporational cooling that reduces the buoyancy. Over the Sudan, the troposphere south of the intertropical convergence zone (ITCZ) is conditionally unstable to great heights, exceeding 200 mb in the south, and it is also potentially unstable to about 500 mb above which level the lapse rate is slightly less than the saturated adiabatic value. Insolation almost always produces some convective clouds, commencing during the morning. Near the ITCZ, the higher temperatures and lower dew-points of the surface air are associated with cloud bases that are higher than those observed at places more than, say, 500 km south of the ITCZ (typically, 3 km above the ground compared with 1 km). Mixing of these clouds with their environment should result in the tops of the great majority not exceeding the break in lapse rate near 500 mb (about 5 km above the ground). Now, calculations[2] suggest that continental cumulus clouds only 2 km deep are unlikely to give any significant rainfall, and this conclusion

has been substantially confirmed by observation.[3 4] By contrast, clouds 4 km deep, and with base temperatures about 20°C, must be expected to give light or moderate showers. Moreover, these shower clouds should develop progressively earlier in the day further south from the ITCZ, at least within the first 500 km. For type (i)[1] stations during July, the sharp maxima in late afternoon or early evening at Wadi Halfa, Kareima and Abu Hamed, contrasting with the broad, flat maxima at En Nahud and Wau, probably reflect this difference in timing of onset of daytime showers. This inference is supported by the progressive change in diurnal pattern at En Nahud and Wau during the rainy season, for it is observed that at the extremes of the season, when the ITCZ lies near each station, the maxima become sharper and they shift to late afternoon or early evening. However, the heaviest rains will fall from tall convective clouds penetrating into the upper troposphere, tops then being above, say, 200 mb. Such clouds are more likely both later in the daily heating cycle and further from the surface position of the ITCZ, i.e. where environment humidities throughout the troposphere are sufficiently high to allow the development of clouds whose cores rise almost undiluted by mixing,[5] and whose core temperatures follow a lapse rate that is almost adiabatic. Near the ITCZ, showers can be expected to fall from only the relatively few clouds whose tops penetrate above 500 mb.

Diurnal variations of both instability and hydrolapse will influence the diurnal distribution of convective rainfall. However, in the absence of direct observations, it is possible only to consider some mechanisms which could lead to diurnal variations of instability and hydrolapse, and then to seek in Table I for evidence supporting the existence of such mechanisms.

The effect on convection of increased afternoon divergence accompanying differential heating of the Nile plains and the Ethiopian highlands has already been discussed. Increased night-time convergence of low-level winds near the ITCZ, although probably contributing to the secondary maximum of rains from stratiform medium clouds around dawn, is unlikely to result in convective storms in the absence of insolation.

Self-propagating storms. Differential horizontal advection should result in an increase of potential instability during the night, when high values of wet-bulb potential temperature are advected from the south in the lower troposphere. Such instability, and the presence of considerable vertical wind-shear, is favourable to the persistence of self-propagating storms on a mesoscale.[6,7] There is some indication that such storms occur over the Sudan. Thus, during the rainiest months, both Wad Medani and Khartoum have maxima near midnight and minima near midday. At Khartoum this pattern persists throughout the rainy season, whereas at Wad Medani it reverts to a type (ii) pattern at the extremes of the season, with a maximum in the early evening. The infrequency of rainfalls during the middle of the day at both stations suggests both the suppression of afternoon convection and the rarity or ineffectiveness of disturbances. However, there is no doubt that convection is an important source of the late afternoon and evening rains because thunder at Khartoum is particularly frequent at that time of day.[8 9,10] A lower, but almost constant, incidence of thunder persists until about dawn, suggesting the presence of self-propagating storms, although the higher incidence of rainfall during the night and early hours compared with the evening indicates

that these storms are likely, in general, to be decaying before they reach Khartoum. The diurnal distribution of squalls there is similar to that of thunder,[10] although Freeman[11] states that fully developed squall-lines are rare at Khartoum.

It has been observed[12] over western Africa that 'tornadoes', showing many of the properties of self-propagating storms, develop preferentially over high ground. The Ethiopian highlands have been suggested[13] as the source of widespread thunderstorms affecting the Sudan, and in particular the western slopes are considered[10,11,14] as being the origin of 'disturbance lines' crossing Khartoum, and observed there by radar. At Kassala, near the potential source region for such storms, Table I shows there is a maximum in rainfall incidence during early evening in most months of the monsoon, weakest in the middle. This is consistent with the occurrence of self-propagating storms. Also, since the distance between Kassala and Khartoum is about 400 km, and since typical storm speeds have been measured[10] by radar at 50–60 km/h from the east, the maximum rainfall incidence at Kassala during the early evening would be consistent with the observed maximum at Khartoum during the night or early hours. Thus, the fragmentary data available suggest that self-propagating storms occur at Khartoum, even though many have probably started to decay, when they would be represented mostly by longer periods of light rain from massive anvil debris moving with the upper easterlies.

At Wad Medani, the diurnal pattern suggests a slightly earlier arrival time than at Khartoum; this is consistent with the former being closer to the Ethiopian highlands. Perhaps the early morning maximum at Kosti is augmented by some of these storms. However, their frequency may well decrease southwards from the ITCZ since Tozi shows a very minor secondary maximum in the early evening. Bhalotra[15] gives the zone 150 to 400 miles south of the ITCZ as being that most frequented by these storms. At El Obeid, the evidence for self-propagating storms is slender. Thus, the diurnal incidence of thunder[8 10] shows a strong maximum in the late afternoon with a feeble secondary maximum in the early morning. However, the strongest squalls, stated to be associated with westward moving squall-lines, are observed to commence near mid-morning, and this is consistent with observed storm speeds and the distance of El Obeid from the highlands. El Obeid is therefore likely to be near the limit of propagation. This agrees with the findings of an unpublished inquiry by Sissons (quoted by Bhalotra[10]) which did not support the idea that squall-lines from Ethiopia could propagate as far as western Africa.

Mid-tropospheric plume from the Ethiopian highlands. The Ethiopian highlands act as a high-level heat source. Warm air, resulting from both insolation and, particularly during the rainiest months, release of latent heat, must therefore be expected to stream downwind as a plume in mid-troposphere. The northern edge of this plume would lie near 15°N, the approximate latitude of the northern tip of the Ethiopian plateau. Below this plume, the low-level south-westerlies would be potentially cooler but beneath its northern edge the temperature differences would decrease or disappear, and the resulting increase in lapse rate would enhance the development of convective clouds. Such a mechanism for the localization of deep convection has been demonstrated by Carlson and Ludlam[7] for plumes originating over the high

plateaux of Spain and Mexico. It is suggested here that a similar plume exists over the eastern Sudan; its presence would not only explain the peculiar persistence throughout the monsoon of night-time rains at Khartoum (dependent on the topographically determined northern edge of the plume), but also contribute to the suppression of afternoon convection over the Nile plains beneath the plume, by decreasing instability during the afternoon and evening. With easterly components of about 20 km/h in mid-troposphere, the plume's influence can be expected to extend several hundred kilometres across the plains.

Radiational cooling of cloud tops. At the height of the monsoon rains, an Ethiopian plume, topped at perhaps 500 mb, is likely to contain much medium cloud. These clouds could contribute to the night-time falls of light rain over the nearby plains, but their frequency should decrease westwards. They would be affected by the night-time increase of convergence near the ITCZ, and perhaps also by night-time cooling of their tops by loss of radiation. An increase of lapse rate within the cloud would then develop, thereby tending to make it denser, particularly by inducing cellular overturning. Coalescence would probably then be accelerated within localized regions of increased liquid water content. After dawn, direct absorption of insolation would warm and disperse or thin the cloud. In this context, it is interesting to note that Fritz and MacDonald[16] have measured, from an aircraft over the U.S.A., a 20 per cent absorption of insolation by extensive layer clouds with tops near 500 to 400 mb. This effect would also lead to an early morning maximum incidence of rain from medium cloud. Both Kraus[17] and Lavoie[18] argue that this mechanism plays an important role over the open ocean in producing a maximum in the early hours, the former for temperate-latitude oceans and the latter for showers from trade cumulus over the low-latitude Pacific Ocean. In both instances, however, the other diurnal mechanisms discussed here are unlikely to be of significance.

Lavoie, in discussing a number of mechanisms for the diurnal variation of rainfall from tropical oceanic cumulus, concluded that the most important factors were the associated variations in depth and stability of the convective layer. Both of these would be modified by low-level convergence, and there is increasing evidence[19] to show that, at least for the tropical Pacific, convergence associated with the atmospheric thermal tides is able to influence significantly the diurnal rainfall pattern, leading to maxima around sunrise and sunset. The first maximum has been observed at some Pacific islands, and it is tempting to consider the dawn rains of the Sudan as being attributable, at least in part, to a tidal effect extending to medium levels. Certainly the widespread occurrence of dawn rains over northern Africa south of the ITCZ, and elsewhere, suggests the presence of a global-scale mechanism related to the daily solar cycle.

Sea-breeze. At Port Sudan, monsoon rainfall is slight, but there is a pronounced afternoon maximum, flat in July, although with a more definite early afternoon peak in August. Both effects suggest the suppression of convection, although at Port Sudan this is more likely to be a result of low-level advection of cool air by the sea-breeze rather than of subsidence associated with heating of the Ethiopian highlands. Whereas both thunderstorm and squall incidence have maxima during the late afternoon,[20] confirming that

the rains at that time are essentially convective in origin, the secondary maximum near midnight is not associated with thunder. These night-time rains probably fall from medium clouds which, however, are much less common around dawn than at, say, Wau or En Nahud. They may well originate as storms that developed earlier over the Asir plateau of Saudi Arabia, the upper parts having drifted in the easterly winds aloft.

Conclusions. The main point of this study has been to present an analysis of the diurnal incidence of monsoon rainfall over the Sudan, and to show that the variations in this incidence from place to place follow a clearly defined pattern. A number of mechanisms have been suggested to account for the variations in diurnal incidence, most of which have already been discussed for other regions. Although, in the absence of direct observations, it is not possible to prove the existence of these mechanisms over the Sudan, evidence has been presented which suggests that a number of them do in fact exist there. In many of them the Ethiopian highlands play a significant role.

Perhaps the main conclusion is a confirmation that the diurnal incidence of tropical rainfall can vary widely, even over an area that is topographically rather uniform. In addition, the following generalizations can be made concerning rainfall over the Sudan.

(i) Day-time convection is the dominant control on rain formation only at places distant from the Ethiopian highlands by about 700 km or more. A maximum incidence is then found in the late afternoon or early evening; it is broader (implying earlier onset) further south from the surface position of the ITCZ.

(ii) Nearer the mountains, the diurnal distribution becomes more even throughout the day, probably a result of the presence of weak disturbances. However, a weak maximum ascribable to day-time convection can still be detected at most places. The weakness of this maximum is probably a result, at least in part, of suppression of convection over the plains caused by afternoon subsidence accompanying the development of a diurnal, large-scale, plains–mountains wind system due to differential heating. Weak suppression also seems to be present at places more distant than 700 km.

(iii) A weak secondary maximum in the early morning is widespread. Its origin is doubtful but may be complex, involving increases during the night of both potential instability and low-level convergence resulting, respectively, from increased differential advection and from an inertial oscillation of the low-level wind field following the rapid release at dusk of drag caused by day-time small-scale convective turbulence. Medium-level clouds appear to account for most of these early morning falls; these clouds may be cooled and thickened as a result of night-time loss of radiation from their tops. The thermal-tide could also contribute to rains around dawn.

(iv) An extensive plume of warm air probably develops daily in mid-troposphere over the Ethiopian highlands, streaming downwind across the Nile plains. Such a plume would not only add to the suppression of day-time convection over the nearby plains, but also

enhance the localization of deep convection to beyond its northern edge. This, together with the increased differential advection accompanying the inertial acceleration of the low-level winds after dusk, probably accounts for the notable evening maximum of convective storms in the Khartoum area. The timing of this maximum remains essentially unchanged throughout the rainy season.

(v) Self-propagating convective storms probably develop over the eastern plains, but more particularly over the western slopes of the Ethiopian highlands, subsequently travelling westwards. Most of these storms seem to decay into periods of lighter rain before reaching the Nile. A few similar rains may also cross the Red Sea from the Asir plateau, to affect the coast of the Sudan around midnight.

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VISIBILITY VARIATIONS AT LONDON/HEATHROW AIRPORT

By J. BRIGGS

Summary. A table is presented for the frequencies of visibility changes in fog at London/Heathrow Airport in periods between four minutes and one hour. The analysis is based on transmissometer records on occasions when visibility was in the range 100–1300 m for periods of three hours or more during June 1965 – September 1966.

Best and Fielder[1] used transmissometer records selected from six days in 1956 to study short-period variations of visibility at London/Heathrow Airport. Recently, occasion has arisen to summarize occurrences of visibility below certain limits at Heathrow, and for this project it was necessary to examine some three years of the transmissometer data. Since the data were basically similar to those used by Best and Fielder it seemed worth while to take the opportunity to repeat their analysis for a much larger sample.

For the project which initiated this work, the transmissometer records for the period June 1965 to May 1968 were examined and a note was made of each individual observation — observations being made at four-minute intervals — for which the indicated visibility was 1300 m or less. In view of the amount of material available it was decided to restrict the extension of Best and Fielder's analysis to those occasions between June 1965 and September 1966 when the indicated visibility was below 1300 m for at least three hours. The base-line of the transmissometer during the period concerned was about 200 m (actually 200 yd) so that estimates of visibility below 100 m could not be made with reasonable accuracy, and the selection of fogs studied was therefore further restricted to exclude periods in which the indicated visibility was below 100 m. The final analysis included some 22 periods of fog, totalling over 145 hours of record.

The percentage changes from the initial visibility were tabulated for time intervals of 4, 8, 12 . . . 56, 60 minutes. When all visibilities initially in the range 200 – 999 m were considered together, the results did not reveal appreciable differences between the occurrences of positive and negative changes, but when the range of initial visibility was subdivided some differences were shown. The lowest sub-range, 200 – 399 m, had more positive than negative changes whereas the highest sub-ranges, 600 – 999 m, had broadly similar frequencies of positive and negative values for the smaller percentage changes but fewer large positive than large negative changes. It is apparent that these differences were largely imposed by the analysis conditions — clearly the limit of 1300 m means that a visibility initially at 800 m cannot change upwards by more than 62·5 per cent or an initial 1000 m by more than 30 per cent, whilst the lower limit of 100 m imposes a limit to negative changes of 50 per cent for an initial visibility of 200 m and of 75 per cent for an initial visibility of 400 m. Since the middle range, 400–599 m, was fairly free from the effects of the artificial limits imposed by the analysis, and since this range had about even occurrences of positive and negative changes, it appeared reasonable that actual occurrences of positive and negative changes of visibility are about even throughout the whole range of initial visibility although the occurrences may be recorded unevenly. Accordingly separate analyses of positive and negative changes were abandoned, and Table I was prepared showing percentage changes (increases or decreases) in various visibility ranges and for a selection of time intervals.

TABLE I—PERCENTAGE OF VISIBILITY CHANGES EXCEEDING SPECIFIED PERCENTAGES OF THE INITIAL VISIBILITY

Time interval	Initial visibility range	Number of occasions*	Specified percentage of initial visibility 10	20	30	40	50	60	70	80	90	100
minutes	*metres*		*per cent*									
4	200–399	248	40.3	24.2	16.1	8.9	7.3	5.6	4.0	3.2	2.8	2.8
	400–599	406	23.4	13.1	7.9	6.0	3.9	2.2	2.2	1.0	0.5	0.2
	600–799	318	30.5	10.7	5.7	2.5	1.6	0.0	0.0	0.0	0.0	0.0
	800–999	365	26.8	9.6	5.5	3.0	1.9	1.1	0.3	0.0	0.0	0.0
8	200–399	245	49.4	33.5	20.4	13.5	11.8	9.0	7.8	6.5	4.9	4.9
	400–599	403	30.5	17.1	11.2	7.4	6.2	5.5	2.2	1.5	1.5	1.0
	600–799	318	39.0	21.4	13.5	6.3	5.4	3.1	0.6	0.0	0.0	0.0
	800–999	363	42.1	16.8	7.4	5.0	2.8	1.9	1.1	0.5	0.0	0.0
12	200–399	247	57.9	40.5	26.3	19.4	15.4	13.7	12.5	11.3	10.5	8.9
	400–599	399	35.5	20.3	14.3	10.5	8.0	6.5	5.0	3.0	2.8	2.3
	600–799	315	50.2	23.5	14.0	9.2	6.0	3.2	1.9	1.6	0.3	0.0
	800–999	356	45.5	19.7	9.3	5.6	2.5	1.4	1.1	0.0	0.0	0.0
20	200–399	244	68.8	48.4	38.9	29.5	25.4	22.5	19.7	18.0	17.2	16.4
	400–599	391	46.0	25.8	16.1	12.8	10.0	7.9	5.4	3.6	3.1	2.0
	600–799	308	58.8	30.5	18.5	13.3	7.5	4.5	2.6	0.7	0.3	0.3
	800–999	347	53.3	28.5	14.7	7.8	4.6	2.3	1.4	0.9	0.0	0.0
28	200–399	238	76.5	54.2	43.7	34.5	29.0	25.6	24.0	22.7	19.7	18.9
	400–599	384	51.3	27.6	21.4	16.1	12.5	9.4	7.6	6.0	5.2	4.2
	600–799	298	65.4	37.2	20.8	14.8	9.7	5.7	3.3	0.3	0.0	0.0
	800–999	336	56.3	32.4	20.2	9.8	6.5	3.0	1.8	0.9	0.0	0.0
36	200–399	233	76.8	54.1	43.8	37.3	30.9	28.3	27.0	24.9	21.5	20.6
	400–599	374	56.4	33.4	23.8	18.2	12.6	10.4	9.4	8.0	6.1	3.7
	600–799	291	71.8	39.2	24.4	16.5	11.3	7.6	3.4	1.4	0.7	0.3
	800–999	326	63.8	33.7	19.3	9.5	5.8	4.0	2.1	0.0	0.0	0.0
44	200–399	226	77.0	58.4	47.5	38.5	31.9	29.6	27.0	25.7	23.0	22.1
	400–599	363	58.9	33 3	24.2	18.7	13.5	9.9	8.5	6.9	5.2	4.4
	600–799	284	75.3	43.3	27.5	17.3	10.9	6.3	2.1	1.4	0.0	0.0
	800–999	318	67.6	37.7	24.5	11.3	4.4	1.1	0.4	0.1	0.0	0.0
60	200–399	209	79.4	65.6	51.7	42.1	35.9	32.1	32.1	28.2	26.3	25.1
	400–599	339	64.0	38.6	24.5	19.8	15.6	12.4	9.4	8.3	5.6	4.4
	600–799	267	78.3	49.4	34.5	23.6	12.0	6.7	3.4	1.9	0.7	0.4
	800–999	304	73.0	45.7	29.9	14.5	6.9	3.6	2.6	0.3	0.0	0.0

* From the period June 1965 to September 1966 occasions were selected when visibility was $\leqslant$ 1300 m for 3 hours or more and when visibility did not fall below 100 m. Percentage changes were based on initial visibility between 200 and 999 m and changes to below 100 m and above 1300 m were excluded.

The table reflects the effects already discussed and, making allowance for these effects, it seems that there is little real difference between the three highest ranges of visibility, and it is considered reasonable to use the figures for the 400 – 599 m range as being typical of the whole range from 400 – 999 m. However, the difference between the 200 – 399 m and the 400 – 599 m range is more substantial. This difference can be partly attributed to the increased relative importance at the lower range of factors which are reasonably constant through the two ranges — for example these ranges are near the optimum range for accuracy using the given base-line length and so observational errors should change little through the range 200 – 599 m. However, it seems likely that the difference between the two lowest ranges may be partly due to more basic physical factors. For visibilities in the region of 200 m most fogs are water-droplet fogs, whereas in the region of 599 m the effects of solid particles are still relatively important. So the increased variability as visibility falls toward 200 m may be due to droplet growth becoming effective on increasing numbers of particles.

The mean changes for time intervals from four minutes up to one hour are indicated in Figures 1 and 2 for the initial visibility ranges of 200 – 399 m and 400 – 599 m respectively. The figures show the expected increase in occurrences of larger changes as the time interval increases. Figure 3 is a plot of the 50 per cent probability value against time for the two ranges. Extrapolation back to zero time of the two curves indicates that the probable error of the observations was about 2 per cent of the actual visibility. Moreover, it seems that the probable change in one minute in visibility is about 2·5 per cent of the initial value when this is in the range 400 – 599 m but is up to 3 per cent of the initial value when this is as low as 200 – 399 m.

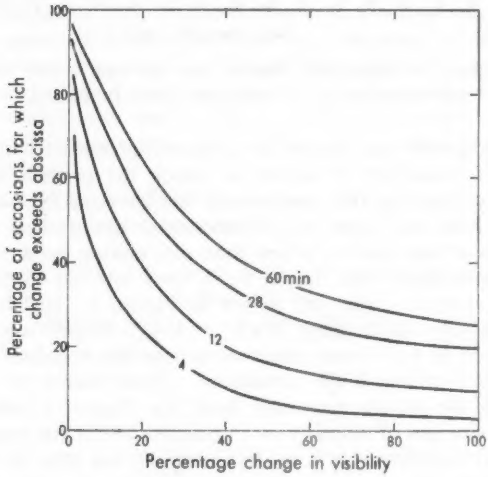

FIGURE 1—CHANGES IN VISIBILITY IN SPECIFIED TIME INTERVALS, INITIAL VISIBILITY 200 – 399 METRES

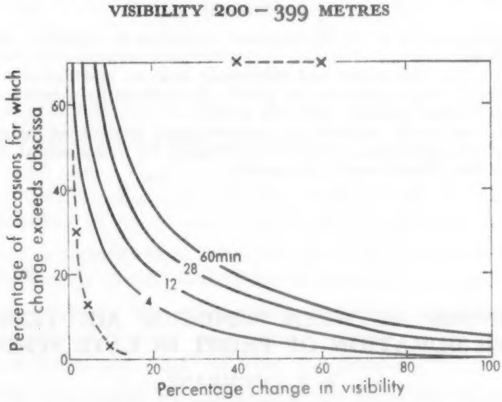

FIGURE 2—CHANGES IN VISIBILITY IN SPECIFIED TIME INTERVALS, INITIAL VISIBILITY 400 – 599 METRES
x – – – x 50-second values (Johannessen[2])

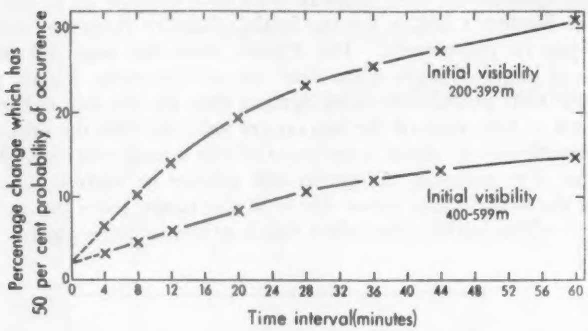

FIGURE 3—CHANGE IN VISIBILITY WHICH HAS 50 PER CENT PROBABILITY OF OCCURRENCE IN A SPECIFIED TIME INTERVAL

As must be expected the results are in good agreement with those of Best and Fielder. It would be of interest to check the general applicability of the figures by comparing the results with similar data for other places but such data are hard to come by. Johannessen[2] has quoted variabilities of transmissivity over time periods of less than one minute for a transmissometer network at Washington. His values for a time interval of 50 seconds and initial visibility below 1 mile are shown in Figure 2. Ito[3] has studied the variability of runway visual range (RVR) at Tokyo Airport and finds that the range of variation in 10 minutes amounts to one-fifth to a half of the runway visual range itself in low RVR conditions. These results are in reasonable agreement with the results presented here, for Figure 1 indicates that 50 per cent of the changes of visibility in 10 minutes are in the range 10 to 50 m when the initial visibility is 200 m, but some 15 per cent of the 10-minute changes exceed 100 m.

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551.524.36:551.524.37

A RELATIONSHIP BETWEEN MINIMUM AIR TEMPERATURES AND DURATION OF FROST IN LATE SPRING

By J. COCHRANE

During April and May most frosts are not accompanied by winds exceeding five knots, and are associated with a diurnal temperature curve of an approximately sinusoidal form.

It would be reasonable to expect that the period of time with temperature below 32°F would increase as minimum temperature decreased, so an attempt has been made to establish a relationship between these factors by examining hourly temperature data for the months of April and May from 1958 to 1967 for three stations — Mildenhall, Gatwick and Pershore.

Most of the original data were in degrees Fahrenheit and this scale has been used in the analysis. Approximate Celsius equivalents are given in parenthesis, where appropriate, but tests and standard errors apply only to the results quoted in Fahrenheit.

All nights with freezing temperatures were considered, irrespective of cloud cover variations. In this article the duration of frost (in hours) was taken as the number of hourly observations with a temperature of 32°F (0°C) or below. As many of the original data were expressed in whole degrees, a few occasions where temperatures were as high as 32·4°F (0·2°C) have been included in the analysis. Occasions when the minimum temperatute qualified, but no single observation was as low as 32°F — i.e. when the temperature fell to freezing-point between two observations — were given a nominal duration of one hour.

The relationship between minimum temperature and duration of frost on 95 nights with freezing temperatures is shown in Table I.

TABLE I—MEAN DURATION OF FROST ASSOCIATED WITH DEGREES OF FROST IN APRIL AND MAY

Degrees of frost		Mean duration of frost	Number of occasions*
Fahrenheit	*Celsius*	*hours*	
0	0	1·0	10
1	0·5	1·8	21
2	1·1	3·6	13
3	1·7	3·9	17
4	2·2	6·0	11
5	2·8	6·4	8
6	3·3	8·0	7
7	3·9	8·7	4
8	4·4	11·0	1
9	5·0	8·3	3

* Number of nights with freezing temperatures at Mildenhall, Gatwick and Pershore during 1958–67.

The correlation coefficient between degrees of frost and duration is 0·98 and regression analysis gives (see Figure 1) :

$$D = 1{\cdot}06\ (32 - T_{\text{min}}) + 1{\cdot}06$$

$$[D = 1{\cdot}90\ (0 - T_{\text{min}}) + 1{\cdot}06 \text{ for temperatures in °C}]$$

where D = duration in hours and T_{min} = night minimum temperature.

The regression is significant at the 0·001 per cent level with standard errors of regression coefficient of 0·03 and of the estimate D, of 0·50.

For practical purposes the relationship may be conveniently reduced to

D = 1 hour per degF of frost + 1 hour.

[D = 2 hours per degC of frost + 1 hour.]

This predictor was tested by calculating the expected duration of frost in April and May for individual nights at Boscombe Down, Waddington and Elmdon and comparing this with the actual duration (as defined above). The distribution of errors (predicted – actual) is given in Table II.

TABLE II—FREQUENCY OF ERRORS IN PREDICTED DURATION OF FROST IN APRIL AND MAY AT SELECTED STATIONS

		Difference (predicted – actual) in hours								
		−5	−4	−3	−2	−1	0	1	2	3
		number of occasions								
Boscombe Down	(1957–67)	1	3			8	5	3	2	
Waddington	(1949–67)	1	1	3	1	6	9	8		1
Elmdon	(1950–67)		1	3	7	11	28	24	10	2
All stations		2	5	6	8	25	42	35	12	3

The mean (observed) duration of frost is 4 hours, the average error, irrespective of sign, is approximately 1½ hours and almost 75 per cent of the errors lie within the range ± 1 hour.

The method cannot give good results for frosts accompanied by wind (relatively infrequent in April and almost unknown in the British Isles in May) and a few occasions where a sinusoidal temperature curve obviously did not exist have been ignored in this check. However, several occasions where the observations indicated a rather flattened curve were included and it is likely that restricting the check to purely radiation nights would give an even closer agreement.

Nevertheless, the size of error involved is sufficiently small for the method to give results which could be useful in planning for frost protection in late spring, but caution should be exercised in applying the results to areas of particularly sandy or very moist soils.

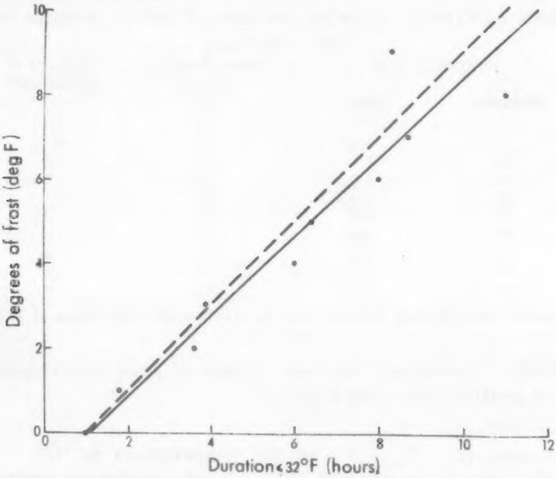

FIGURE 1—REGRESSION OF DURATION ON DEGREES OF FROST

— — — — D = 1 hour per degF of frost + 1 hour

———— $D = 1{\cdot}06\,(32 - T_{\min}) + 1{\cdot}06$ hours

It is theoretically probable — and in fact Figure 1 hints — that the relationship does not remain linear for minimum temperatures below about 25°F (−4°C), and extrapolation for temperatures outside the range of this analysis would not be justified unless a much larger margin of error could be accepted.

Acknowledgement. I am indebted to Messrs A. J. Heasman and R. P. Rumney for work on the extraction of basic data.

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PREDICTION OF MONTHLY RAINFALL OVER ENGLAND AND WALES FROM 15-DAY AND MONTHLY MEAN TROUGHS AT 500 mb

By R. MURRAY

Summary. An examination is made of the positions of mean troughs at 500 mb on the 15-day time-scale from America to Europe in connection with predicting monthly rainfall over England and Wales. Although the 15-day means are not as helpful as the 30-day mean troughs in monthly rainfall prediction, consideration of mean troughs on both time-scales appears to improve the monthly rainfall forecasts.

Introduction. In a recent paper Ratcliffe[1] developed simple synoptic criteria relating the positions of the American and European 500-mb monthly mean troughs at 50°N to monthly rainfall over England and Wales in the following month. It was thought desirable to investigate whether the prediction of monthly rainfall would be improved further by taking account of 15-day mean troughs at 50°N as well as the monthly mean trough positions. For convenience in computation the mean data were for three pentads from 1 January to 13 August and from 3 September to 31 December, but for four pentads from 14 August to 2 September.

Empirically derived criteria concerning the longitudes of the mean troughs were used by Ratcliffe[1] for predicting rainfall one month ahead during the April–August period (prediction for months May–September); slightly different criteria were used for the September–November period (prediction for months October–December), and for the December–March period (prediction for months January–April). In this note these criteria were applied to the 15-day mean trough positions for the period 1949–66.

Here F_1, F_2 and F_m have the following meanings :

F_1 = prediction based on the positions of the 15-day mean troughs at 500 mb in the first half of month,

F_2 = prediction based on the positions of the 15-day mean troughs at 500 mb in the second half of month,

F_m = prediction based on the positions of the monthly mean troughs at 500 mb.

Period April–August. There were only 12 occasions when F_1, F_2 and F_m all suggested the same prediction. It might be thought that the accuracy of such predictions would be high. In fact the mean score for these 12 cases is 1·8 compared with 1·7 for the 77 cases given in Ratcliffe's Table I. The scoring system used here is the one employed in the Synoptic Climatology Branch of the Meteorological Office (see Freeman[2]). In this system a correct forecast is allocated 4 points. An incorrect forecast of average rainfall is given −2 points. A forecast of below (or above) average rainfall is given 0 or −4 points if it is one or two terciles in error respectively. Over a long period forecasts no better than chance would give a zero score. Forecasts with mean scores greater than about 1 are generally satisfactory and those with mean scores greater than 2 are usually considered to be very good.

It is of interest that on occasions when F_m could not be made there were no occasions when F_1 and F_2 were in agreement. However, on six occasions F_m was made, yet neither F_1 nor F_2 could be made since the half-monthly

troughs were not located in the proper longitude zone near the British Isles (five of these forecasts were correct). There were several other possible combinations of F_m, F_1 and F_2 (e.g. no F_m, F_1 and F_2 different), but in general these separate classes involved quite small numbers. Nevertheless it was reasonable to combine some categories, with the results as indicated in Table I.

TABLE I—MEAN SCORES ACHIEVED WITH SPECIFIED PREDICTIVE CONDITIONS IN 1949–66 DURING THE PERIODS *(a)* APRIL–AUGUST, *(b)* SEPTEMBER–NOVEMBER AND *(c)* DECEMBER–MARCH; IN EACH PERIOD FORECASTS ARE FOR THE FOLLOWING CALENDAR MONTH

Type	Period *(a)* Number of forecasts	Period *(a)* Mean score	Period *(b)* Number of forecasts	Period *(b)* Mean score	Period *(c)* Number of forecasts	Period *(c)* Mean score
1. F_m and F_1 agree, no F_2 or it disagrees	16	2·2	14	1·5	6	1·3
2. F_m and F_2 agree, no F_1 or it disagrees	15	1·1	5	4·0	7	4·0
3. F_m and F_1 or F_2 or both agree	43	1·7	23	1·8	23	2·2
4. F_1 only	63	0·9	30	0·1	35	1·0
5. F_2 only	53	0·5	32	0·4	27	0·6
6. F_m only (i.e. Ratcliffe's procedure)	77	1·7	43	1·5	49	1·0

From Table I (column *(a)*) it is seen that forecasts on the basis of F_1 only (type 4) or F_2 only (type 5) are generally inferior to F_m. There is a suggestion that the trough positions in the first half of the month are at least as important as trough positions in the second half of the month (compare types 1 and 4 with 2 and 5).

Examination of the contingency tables from which the mean scores of section *(a)* of Table I were obtained shows quite clearly that the main success comes from the prediction of the wet tercile R_3 (R_3 = wet, R_2 = average, R_1 = dry). For example, in type 1 the 8 forecasts of R_3 were all correct; in type 2 the 6 forecasts of R_3 resulted in 5 R_3 and 1 R_2 months; in type 3 the 20 forecasts of R_3 were followed by 15 R_3 and 5 R_2 months. In none of these three types were the R_2 or R_1 forecasts particularly successful. The detailed data used in type 3 are shown in Table II. The chi-square value is about 15 which implies significance at the 0·5 per cent level.

TABLE II—RELATION BETWEEN THE POSITIONS OF MEAN TROUGHS AT 500 mb IN A MONTH DURING PERIOD APRIL–AUGUST AND THE RAINFALL OVER ENGLAND AND WALES IN THE FOLLOWING CALENDAR MONTH. PREDICTIONS WERE MADE WHEN THE MONTHLY MEAN TROUGH POSITION AGREES WITH EITHER OR BOTH 15-DAY MEAN TROUGH POSITIONS, AND TROUGHS EXIST BETWEEN 20°W AND 25°E

Actual England and Wales rainfall in following months (terciles)	**A** Troughs at or west of 65°W* and between 20°W and 5°E*. Forecast R_3 (wet)	Trough exists between 20°W and 25°E but neither **A** nor **B** satisfied. Forecast R_2 (average)	**B** Troughs 45°–65°W* and 5°E*–25°E. Forecast R_1 (dry)
Actual R_3	15	1	4
Actual R_2	5	4	4
Actual R_1	0	4	6

* Following Ratcliffe,[1] if trough is exactly on one of these longitudes, consider only the other trough. If both troughs are marginal, forecast normal.

Period September–November. There were no cases where both F_1 and F_2 agreed whilst F_m was different or not applicable. Nor were there any cases with F_1, F_2 and F_m all different. However, on six occasions F_1, F_2 and F_m were all in agreement but surprisingly only one forecast was fully correct. An interesting case arose in which there was no F_m (i.e. the monthly mean trough was not in a suitable position) but F_1 and F_2 differed (i.e. the 15-day European troughs existed). In 14 examples of this type results were quite useless; indeed much better forecasts would have been made by forecasting the opposite rainfall classes when R_3 and R_1 were indicated by F_1 or F_2.

The mean scores which applied to specified forecasts categories are given in Table I. It is clear that forecasting monthly rainfall on the basis of the mean trough positions in either the first half- or the second half-month is not helpful (see types 4 and 5). The types 2 and 3 suggest that rather better forecasts were made when some account was taken of the 15-day mean trough positions as well as of monthly trough positions. However, type 2 consisted of only four cases and the mean score must therefore be regarded as fortuitous. Even type 3 consisted of rather few cases.

Period December–March. On two occasions F_1 and F_2 were in agreement but no F_m applied; no forecast was correct. There were no occasions when F_1 and F_2 agreed and each differed from F_m. On five occasions the only possible prediction on the basis of trough positions was on the first half-month data; the forecasts were all correct. On the other hand, each of the three predictions made on the basis of the second half-month trough positions (i.e. F_2 but no F_1, F_m) was in error by one tercile. The categories referred to in the preceding two sections under *(a)* and *(b)* in Table I are given under *(c)* in the same table.

Predictions made on the basis of mean trough positions in the first half of the month (i.e. type 4 which takes no account of the whole month or the second half-month positions) were about as accurate as forecasts on the basis of the whole months trough positions (i.e. type 6). However, type 5 predictions were marginally inferior to both types 4 and 6. Types 2 and 3 predictions gave the best results, although the exceptional results under type 2 cannot be regarded as typical in view of the smallness of the sample. The occasions which made up the type 3 cases are given in Table III. The data are insufficient for statistical testing, but it is of interest that the chi-square value is about 16 which suggests that the results are significant at the 0·5 per cent level.

Conclusions. Applying Ratcliffe's criteria for monthly mean 500-mb positions at 50°N to 15-day mean trough positions, does not in general result in materially better forecasts of monthly rainfall for England and Wales than are given by considerations of monthly mean trough positions alone. This result is perhaps not surprising in view of the fact that the Ratcliffe method was developed on monthly means. A similar method developed on 15-day means with the specific objective of predicting monthly mean rainfall would no doubt be based on rather different trough boundaries in the different seasons, and it might be expected to apply with more success than the procedure used here. Furthermore, there is the possibility of the existence of fluctuations in atmospheric circulation with periods around a

TABLE III—RELATION BETWEEN THE POSITIONS OF MEAN TROUGHS AT 500 mb IN A MONTH DURING PERIOD DECEMBER–MARCH AND THE RAINFALL OVER ENGLAND AND WALES IN THE FOLLOWING CALENDAR MONTH. PREDICTIONS MADE WHEN THE MONTHLY MEAN TROUGH POSITION AGREES WITH EITHER OR BOTH 15-DAY MEAN TROUGH POSITIONS, AND MEAN TROUGHS EXIST BETWEEN 20°W AND 25°E

Actual England and Wales rainfall in following months (terciles)	A Troughs at or west of 75°W* and between 20°W and 5°E*. Forecast R_3 (wet)	Trough exists between 20°W and 25°E but neither A nor B satisfied. Forecast R_2 (average)	B Troughs 50°–75°W* and 5°E*–25°E. Forecast R_1 (dry)
Actual R_3	3	2	1
Actual R_2	1	5	0
Actual R_1	0	3	8

* Following Ratcliffe,[1] if trough is exactly on one of these longitudes consider only the other trough. If both troughs are exactly marginal, forecast normal.

month, as suggested, for example, by a table of synoptic 'singularities' presented by Lamb,[3] in which the dates of several singularities tend to be separated by intervals of roughly a month. If such 30-day fluctuations occurred at all widely in atmospheric processes then clearly 15-day means could be seriously affected by them; some features on the 15-day time-scale might not persist owing to domination by the 30-day wave. However, there is no conclusive evidence in this study that the smaller success achieved in using 15-day rather than 30-day means for predicting rainfall on the monthly time-scale can really be attributed to the existence of atmospheric oscillations with periods about 30 days.

There are, nevertheless, some combinations of 15-day and monthly mean trough positions which tend to improve the rainfall predictions. For the April – August period, predictions of wet months are very successful when the monthly and at least one half-monthly trough indicator are in agreement. For the September – November period there are apparently marginally better predictions when the monthly and at least one half-monthly trough indicator agree, especially when the second half-monthly and monthly predictions are in agreement. However, the sample is too small for firm conclusions on this point. Finally, for the December – March period, there is a definite indication that the forecasts are more accurate when at least one of the half-monthly predictions, especially when this refers to the second half of the month, agrees with the prediction made from the monthly mean trough positions.

It is likely that 15-day mean trough positions at 500 mb will prove useful in predicting rainfall over 15-day periods. However, progress in the examination of rainfall prediction on this time-scale awaits the completion of the data processing of daily rainfall from stations selected to represent rainfall over England and Wales.

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THE ONSET OF THE INDIAN SOUTH-WEST MONSOON AND EXTRATROPICAL 500-mb TROUGH AND RIDGE PATTERNS OVER EUROPE AND ASIA

By P. D. de la MOTHE and P. B. WRIGHT

Summary. The 500-mb trough and ridge patterns over Europe and Asia are examined in order to seek a relationship with the onset of the Indian south-west monsoon. In particular the behaviour of the Asian ridge and the wavelength variations across it are studied. It is demonstrated that these variations in association with a mean trough at 500 mb near longitude 75°E in middle latitudes are closely linked with the reversal of wind at 200 mb over northern India and the onset of the south-west monsoon.

Introduction. The onset of the Indian south-west monsoon in late May/early June has been extensively studied from many points of view, particularly since the beginning of what might be termed the aerological era, roughly 1945, and it has long been recognized that the onset and withdrawal of the monsoon are part of general circulation changes occurring in the tropical and subtropical zones. This has been amply demonstrated by many authors, notably Sutcliffe and Bannon,[1] Yeh, Dao and Li,[2] Lockwood[3] and Wright.[4]

However, in spite of availability of substantial middle- and upper-tropospheric data, not much attention has been paid to relationships which are known to exist between the onset of the monsoon and changes in the circumpolar westerlies of middle and high latitudes. Furthermore, the studies made so far have not generally covered a long sample of years. In some cases, data for only one or two years have been examined.

One of the earliest investigations was that of Yin.[5] This was a comprehensive study of the monsoon in 1946 with particular reference to the 500 mb flow and associated jet fluctuations in northern latitudes. Yin first demonstrated that the onset of the monsoon was related to the northward shift of a low-latitude westerly jet. The northward movement of this jet, from the south to the north of the Himalayas, is linked with a shift of a mean trough from about 90°E to near 80°E. He also showed that the movement of the jet was correlated in time with a general rearrangement of the long-wave pattern in the northern hemisphere.

Sutcliffe and Bannon[1] suggested that conditions in middle latitudes may be relevant to the monsoon process, since they 'are known to show very large variations from year to year over Europe between extremes of persistent blocking and progressive westerlies.'

Flohn[6] considered that a factor of importance to the onset of the monsoon was the formation of a mean trough near 68°E correlated with a west-north-westerly flow over central and eastern Europe.

Ramaswamy[7] published 15-day mean 500-mb charts associated with an abnormally early and late onset of the monsoon, but the major part of his work[8,9] showed that monsoon 'breaks' were related to 500-mb middle-latitude patterns over Eurasia.

In the present work it was decided to look for a relationship between the onset of the monsoon and the pentad(5-day period)-mean trough and ridge positions at 500 mb over the eastern hemisphere between latitudes 40° and 70°N during April, May and June of the years 1949–66.

First, a study was made of the 16-year (1949–64) average positions, and then individual years were considered.

Seasonal variations in 16-year average positions of troughs and ridges. The 16-year average of the positions of the 500-mb pentad-mean troughs and ridges at 50°N shows several marked changes occurring in the Eurasian sector during the first six months of the year (Figure 1, reproduced from de la Mothe[10]).

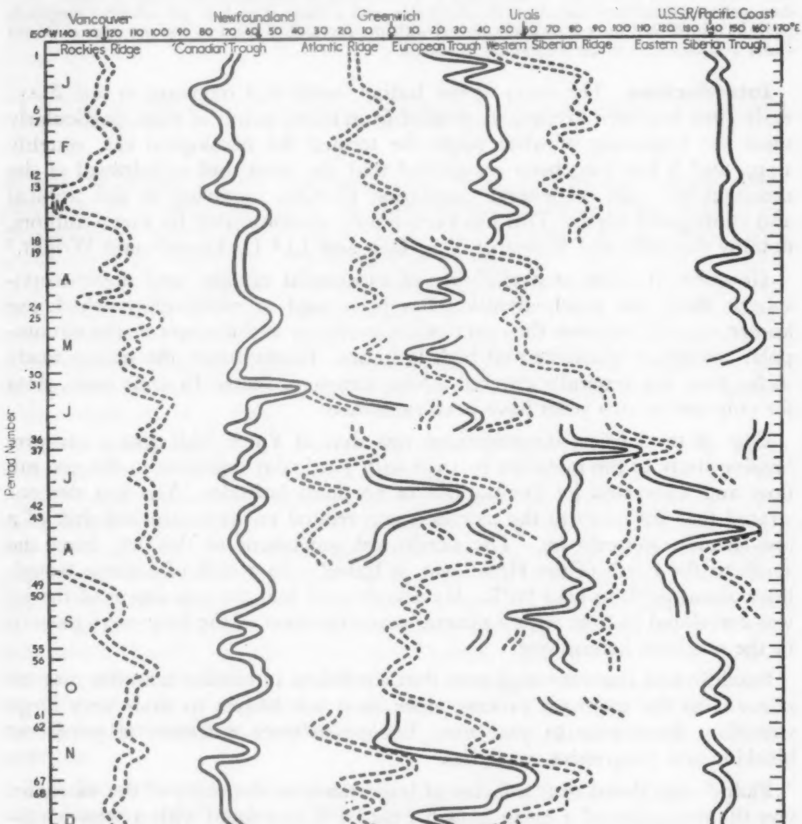

FIGURE 1—AVERAGE POSITIONS OF PENTAD-MEAN TROUGHS AND RIDGES AT 500 mb AROUND 50°N. PERIOD 1949–64

During January to March the Asian (western Siberian) ridge lies in the sector 70° – 90°E; there is a deep trough at 140° – 150°E, and a shallower trough (the European trough) between 30° and 50°E. In pentad 1–5 April a change occurs, and by 6–10 April a new régime has become established; the Asian ridge is now at 50° – 60°E, and the European trough is shallow and

fluctuating between 10° and 30°E. The deep trough over eastern Asia, however, has moved slightly eastwards to between 150° and 160°E. This régime persists until 21–25 May.

In pentad 26–30 May another marked change occurs. The deep trough over eastern Asia, after filling gradually during the spring, moves eastwards into the Pacific. The Asian ridge moves east to about 90°E, and the trough over Europe progresses eastwards reaching longitude 70°E in pentad 5–9 June.

Thus there are two major changes. The first is in early April, the second in late May, and both changes occur at about the same time as those taking place in the tropical flow patterns described by Wright.[4] The first change in April corresponds to the decrease in the 200–mb zonal component at Bombay, while the second relates to the seasonal rearrangement of tropical patterns which is associated with the onset of the monsoon.

The mean trough which becomes established near 70° – 75°E in pentad 5–9 June remains near these longitudes throughout the monsoon period, thus replacing a mean ridge which was noticeable in the winter up to the end of March.

This particular change is associated with a general decrease in wavelength, since one or more new subsidiary mean troughs and ridges are apparent at this time and remain a feature of the summer season around the hemisphere.

It is worth noting that the date of the establishment of the mean trough near 70–75°E, i.e. pentad 5–9 June, is coincident with the average date of the onset of the monsoon over the west coast of India, as derived by Ramdas[11] *et alii.*

Seasonal variations of the 16-year average wavelength. In a previous note by de la Mothe,[10] it was suggested that the wavelength variations of the mean flow at 500 mb in middle latitudes could be related to seasonal circulation changes in adjacent sectors of the hemisphere. The graph showing wavelength variations across the Asian ridge is reproduced in Figure 2. There are once again two clear and well-marked changes, one in the first half of April, the other in late May/early June. Between these two distinct periods of change there is an intermediate period when the wavelength across the Asian ridge, instead of decreasing, shows an average increase from 81° of longitude in pentad 16–20 April to 97° in pentad 16–20 May. Subsequently, there is a dramatic shortening of mean wavelength to 65° in pentad 31 May–4 June. Thus, between the winter régime of January, February and March and the summer régime of June, July and August, there are clearly two profound changes of the long-wave pattern in the Eurasian sector of the hemisphere.

It is worth noting that as far as May and June are concerned the wavelength variations agree with and confirm, over a longer period, those shown in the work of Yin[5] and also Yeh, Dao and Li.[2] These authors reproduced trough–ridge diagrams, for 1946 and 1956 respectively, showing variations of pentad-mean 500-mb contour heights between latitudes 40° and 70°N as functions of longitude and time. The diagrams clearly show the maintenance, or slight increase, of wavelength across the Asian ridge during May prior to the breakdown of the pattern at the end of May, so that by early June a new régime of shorter wavelengths prevails.

The foregoing suggests that a study of individual years would be justified.

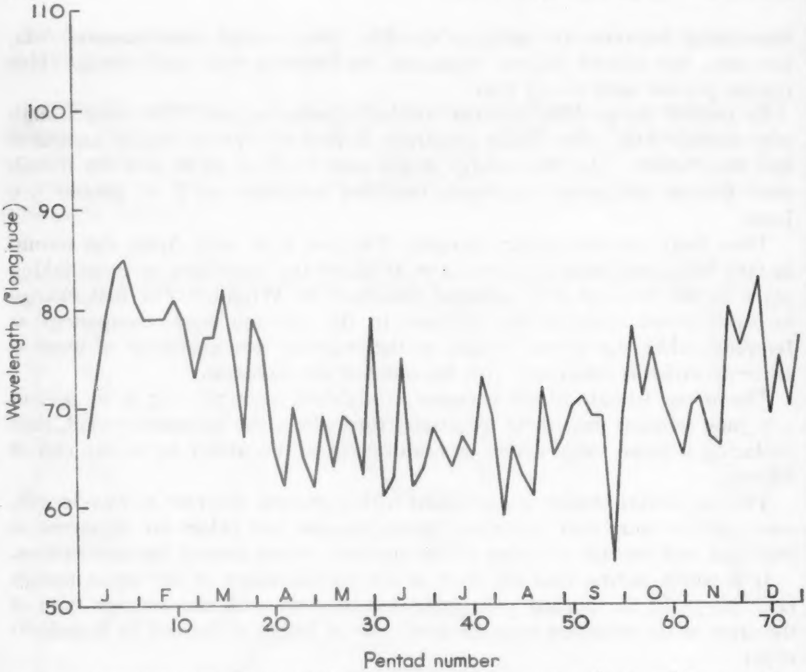

FIGURE 2—AVERAGE WAVELENGTH ACROSS ASIAN RIDGE (500 mb) AT 50°N. PERIOD 1949–64

Seasonal variations in positions of troughs and ridges during individual years. To study each year separately a preliminary examination was made of the trough-ridge positions around latitude 50°N. However, it soon became apparent that the use of a single latitude alone was unsatisfactory, mainly because the eastward flow of troughs and ridges from pentad to pentad trended to obliterate longer-term changes.

Therefore, to extend the investigation to all latitudes, circumpolar 500-mb contour charts were produced for the northern hemisphere to latitude 35°–40°N, covering May and June of each year, 1949–66. As Yin[5] and others have stressed the importance of the Himalayan/Tibetan plateau in connection with circulation changes occurring at the time of the onset of the monsoon, the high ground of the plateau above 10 000 ft (3 km) was marked on each of the 500-mb pentad charts. Next, the advance of the monsoon boundary at the surface (northern limit of monsoon or NLM) was plotted as a daily position. The data for this were taken from the *Indian Daily Weather Report*[12] which since 1956 has published daily 1·5-km flow charts showing the NLM. For the period 1949–55 it was necessary to examine the 1·5-km flow charts, from which, with the aid of the synoptic review and relevant rainfall data, a reasonably accurate position of the NLM was derived.

From consideration of the wavelength changes peculiar to May and June, and bearing in mind some of the factors deemed important by previous authors, it was decided that the following features should be considered when examining the 500-mb pentad-mean contour charts for each individual year :

(i) The maintenance or slight increase of mean wavelength across the Asian ridge during late April and May leading to a sudden and dramatic increase in wavelength about the end of May.

(ii) The decrease of wavelength likely to be associated with the formation of a trough fluctuating between 70° and 80°E, on average near 75°E (i.e. just west of the Himalayas), and possibly extending northwards to the polar vortex, or at any rate to high latitudes.

(iii) An assessment of the general character of the flow over Europe and western Asia between the time of occurrence of (i) and (ii) and the onset of the monsoon, i.e. whether zonal or meridional flow prevails, obtained subjectively by an examination of the sector from 40°–70°N between Greenwich and 90°E. This assessment is given in Table I.

TABLE I—SUBJECTIVE ASSESSMENT OF 500-mb FLOW OVER EUROPE AND WESTERN ASIA PRIOR TO AND AT TIME OF MONSOON ONSET

Year	Assessment	Year	Assessment
1949	Meridional	1958	Meridional
1950	Zonal	1959	Zonal, becoming meridional
1951	Meridional in west, zonal in east	1960	Meridional
1952	Meridional	1961	Zonal
1953	Meridional	1962	Zonal, becoming meridional
1954	Meridional	1963	Meridional in west, zonal in east
1955	Meridional	1964	Meridional, becoming zonal in high latitudes
1956	Weakly zonal, becoming meridional	1965	Zonal, becoming meridional in high latitudes
1957	Zonal	1966	Meridional

The procedure adopted in practice was to measure the wavelengths between the relevant troughs and ridges in the Eurasian sector on each chart using a transparent overlay. Since the latitude zone under consideration was 40°–70°N, it was decided to take measurements along latitude 55°N. As a further aid, trough–ridge diagrams were available for each year at latitude 50°N. In this way, a close study was made of the flow pattern and wavelength changes in latitudes 50°–55°N, which were considered to be reasonably representative of the circumpolar westerlies between 40° and 70°N, at least as far as wavelength measurements were concerned. It must be pointed out here that, for a given pentad of the year, mean wavelengths observed on individual pentad charts are often appreciably different from wavelengths measured on a long-period mean chart for the same pentad. This is a natural result of the fact that in the longer-term averaging process, many of the minor oscillations are smoothed out or removed.

The dates of the various changes were found and Figure 3 shows diagrammatically the results of this examination. The diagram presents also the dates of a further event, namely, the collapse of the 200-mb westerlies at Bombay. As previously mentioned, it has been well established by several authors that the disintegration of the 200-mb low-latitude westerlies is closely related to the onset of the monsoon. Therefore it seems logical to link this event with what may be happening at about the same time at 500 mb in middle and high latitudes.

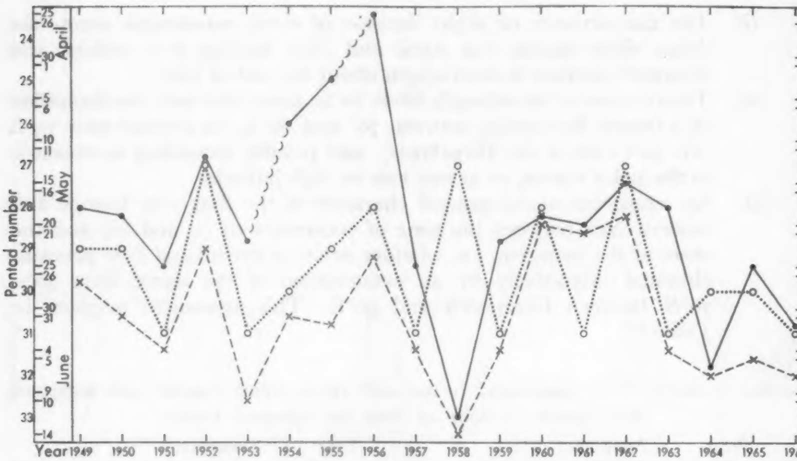

FIGURE 3—DIAGRAMMATIC REPRESENTATIONS OF YEAR-TO-YEAR VARIATIONS

•———• 1949–53 Date of first easterlies at 200 mb at Aden (Sutcliffe and Bannon[1]).
1954–55 Middle day of last pentad with a mean westerly component at 200 mb at Aden (Lockwood[3]).
1956–66 Date when 200-mb westerly component at Bombay fell below 5 kt (Wright[4]).

o . . . . . o Date of major wavelength changes across Asian ridge in middle latitudes.

x – – – – x Date when northern limit of monsoon (NLM) reached 13°N on west coast of India.

For the years 1956–66, the dates shown are those derived by Wright[4] from running pentad-means of the 200-mb zonal wind component at Bombay. For the period 1949–55, the dates shown are those derived by Sutcliffe and Bannon[1] and by Lockwood.[3] These dates, however, refer to chagnes of the 200-mb zonal wind component at Aden. The use of Bombay and Aden 200-mb data on Figure 3 was considered justified because both stations are fairly close in latitude and both are reflecting essentially the same circulation change in their high-level wind data although at slightly different times. A comparison of the overlapping period of the two sets of data shows that both events are clearly part of the same process of change, although the Aden change is generally about a pentad earlier than that at Bombay.

Figure 3 also includes the date of the onset of the monsoon, defined in this instance as the date when the NLM reaches 13°N on the west coast of India.

Discussion. It is clear from Figure 3 that there is a close relationship between the various events. However, certain years require comment.

In 1954 and 1955 the 200-mb changes shown in Figure 3 appear to have occurred much earlier, relative to the other changes, than in the remaining years. This may be the result of the criterion used for these two years in Figure 3; the ten-day mean charts of the 200-mb wind field for 1954–60 published by Lockwood[3] suggest that the decrease of Bombay zonal component below 5 kt normally occurs after the last pentad-mean westerly component is observed at Aden.

As regards 1956, the position is not clear. Although the *Indian Daily Weather Report* gives the date of onset of the monsoon as 24 May, as shown in Figure 3, many indications suggest (see p. 311, Wright[4]) that a surge of the monsoon occurred at the beginning of May. Upper tropospheric changes in the tropics support this. However, there was no sign of the formation of a 500-mb trough at 75°E until pentad 16–20 May, and then only rather weakly. It was not until pentad 26–30 May that the wavelengths decreased over a wide sector with the advent of a deeper trough near 75°E. Yeh *et alii*,[8] who studied 1956 in some detail, confirm this on their trough–ridge diagrams of pentad-mean 500-mb contour heights between 50° and 70°N.

The year 1961 is also puzzling; the temperate-latitude changes appear to have played little part in the monsoon onset.

In 1958, and to a lesser extent 1964, both the onset of the monsoon and the decrease in the Bombay wind component occurred later than the changes at 500 mb. It is notable that 'Relationship III' of Wright,[4] which related the onset of the monsoon to the change in wind field which occurs during April, also broke down in those years. The present results confirm the suggestion that in those two years there was some other factor which delayed the establishment of the monsoon flow patterns after the middle-latitude 500-mb flow had become favourable for the change.

To sum up, it seems that in 1958 and 1961, and perhaps in 1956 and 1964, the behaviour of the middle-latitude 500-mb flow played little obvious part in the mechanism of the onset of the monsoon. For the majority of years, however, the sequence of events seems to be as follows :

(i) The 200-mb subtropical westerly jet over northern India collapses and another jet forms just north of the Himalayas.

(ii) Similarly the 500-mb westerly flow is induced to flow north rather than south of the Himalayas.

(iii) A mean 500-mb trough becomes established near 75°E, partly orographically imposed, and partly as a result of the seasonal decrease of wavelengths occurring about this time in the circumpolar westerlies.

(iv) The establishment of this 500-mb mean trough near 75°E, with short wavelengths up- and down-stream, and on average, meridional flow (see Table I), results in a marked southerly component over the Indian subcontinent.

(v) The advance of the monsoon follows immediately after these events, although in a minority of years it is evident that the 500-mb circumpolar patterns play little part and the underlying mechanism must be some other factor the influence of which is perhaps confined to tropical latitudes, and which also influences the rapid decrease of wind speed at Bombay.

Figures 4–9 show the sequence of events at 500 mb in 1949 which was typical in most respects. Middle-latitude wavelengths which had been long (Figures 4 and 5) decreased considerably in pentad 21–25 May (Figure 6), the 200-mb change having already occurred on 18 May (see Figure 3). The trough is well established and extends northwards to the polar vortex in

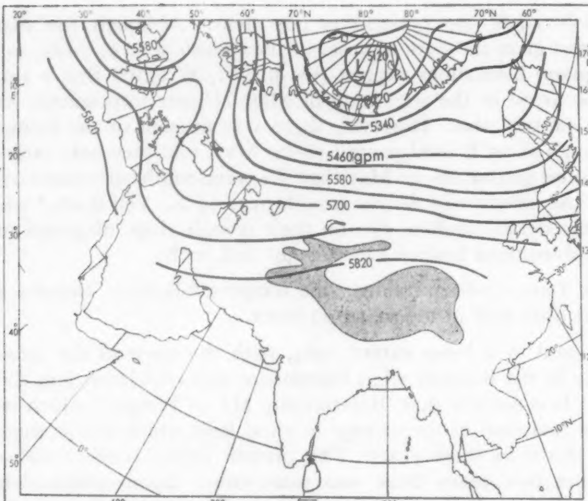

FIGURE 4—500-mb CONTOUR CHART, PENTAD-MEAN VALUES FOR PENTAD 1–5 MAY 1949

Stippled area is ground over 10 000 ft in the Himalayas

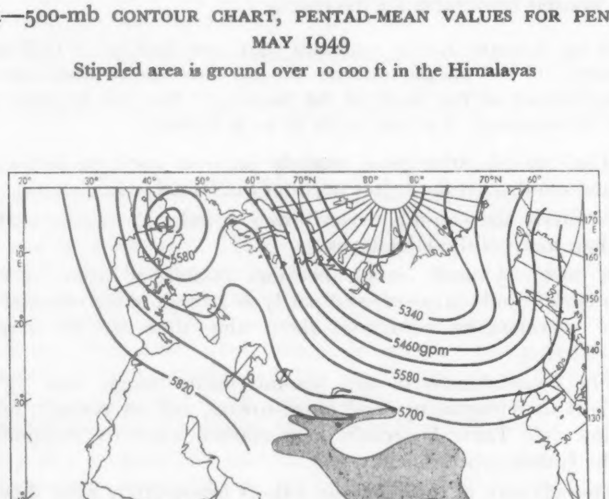

FIGURE 5—500-mb CONTOUR CHART, PENTAD-MEAN VALUES FOR PENTAD 11–15 MAY 1949

Stippled area is ground over 10 000 ft in the Himalayas

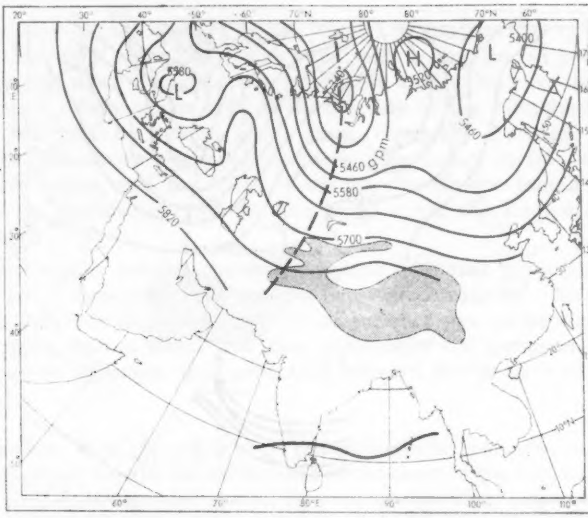

FIGURE 6—500-mb CONTOUR CHART, PENTAD-MEAN VALUES FOR PENTAD 21–25 MAY 1949

Stippled area is ground over 10 000 ft in the Himalayas
——— NLM boundary on middle day of pentad
— — — Trough lines

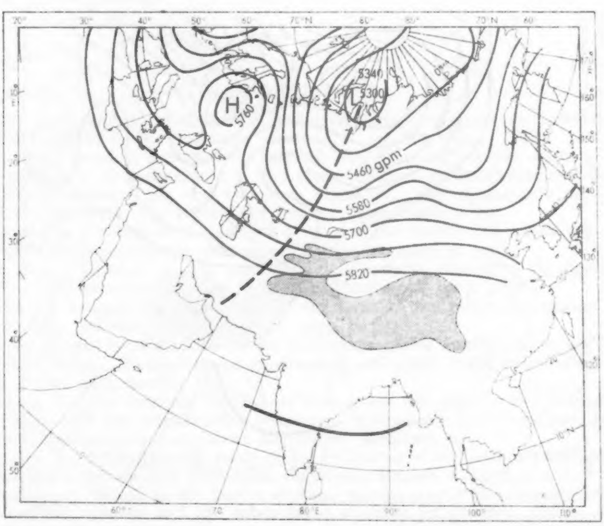

FIGURE 7—500-mb CONTOUR CHART, PENTAD-MEAN VALUES FOR PENTAD 31 MAY – 4 JUNE 1949

Stippled area is ground over 10 000 ft in the Himalayas
——— NLM boundary on middle day of pentad
— — — Trough lines

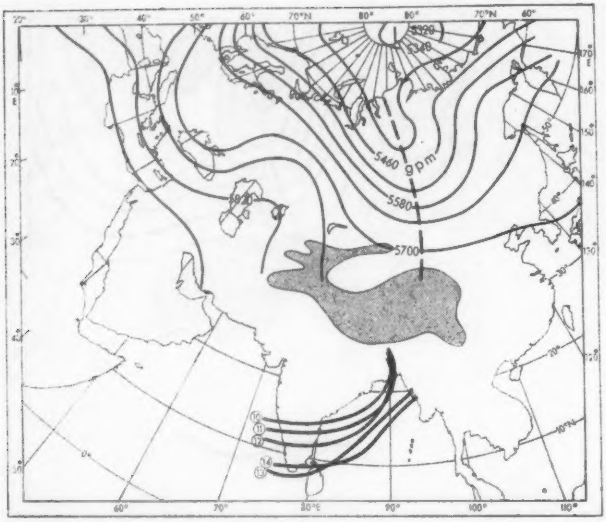

FIGURE 8—500-mb CONTOUR CHART, PENTAD-MEAN VALUES FOR PENTAD 10–14 JUNE 1949

Stippled area is ground over 10 000 ft in the Himalayas
——— NLM boundary on each day of pentad
— — — Trough lines

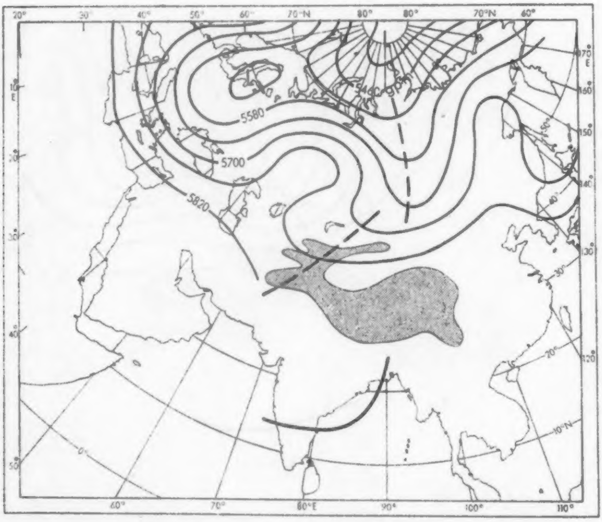

FIGURE 9—500-mb CONTOUR CHART, PENTAD-MEAN VALUES FOR PENTAD 20–24 JUNE 1949

Stippled area is ground over 10 000 in the Himalayas
——— NLM boundary on middle day of pentad
— — — Trough lines

pentad 31 May–4 June (Figure 7) and the NLM has reached 15°N, having already passed 13°N on 27 May. It is interesting to note that in pentad 10–14 June (Figure 8) there is a temporary weakening and recession of the monsoon as the trough briefly moves to the eastern side of the Himalayan/Tibetan plateau. However, by pentad 20–24 June (Figure 9) a trough is forming west of the Himalayas again, although slanting rather steeply northwards to the polar vortex, and the NLM re-advances across the Indian peninsula. Note also the meridionality of the flow right across the Europe/Asia sector at this stage.

The dates of the 500-mb changes indicated in Figure 3 (excluding 1949, 1955 and 1965) show clear evidence of a two-year periodicity. This periodicity appears to influence the date of onset of the summer 500-mb régime in middle latitudes more than it affects the date of onset of the monsoon. Thus, by taking two-year averages, the correlation between the two curves would be increased.

Conclusion. The 500-mb flow in the circumpolar westerlies over Eurasia plays a significant role in the mechanism of the onset of the Indian south-west monsoon and close attention should be paid to the Asian ridge and changes of wavelength across it at this time. It is conceivable that, after due allowance has been made for the effect of any two-year oscillation, a useful forecasting aid could be evolved by careful evaluation of the behaviour of the mean wavelength across the Asian ridge during April and May, which has been shown to be closely correlated with other events already known to precede the onset of the monsoon.

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REVIEWS

The Antarctic atmosphere: Climatology of the troposphere and lower stratosphere, Folio 4, and *Climatology of the surface environment, Folio 8,* by W. S. Weyant (text). Antarctic map folio series, edited by Vivian C. Bushnell. 430 mm × 280 mm, pp. 4 with 8 plates, and pp. 4 with 13 plates. American Geographical Society, Broadway at 156th Street, New York, 1966 and 1967. Price: $29·50 per set of 8 folios.

These two well-printed folios compiled by the National Weather Records Center with texts by W. S. Weyant provide a useful, if limited, English-language guide to the main climatological features of the Antarctic and the southern oceans. Because of the paucity of data over the oceans some of the plates should be treated with caution and not be taken to be as definite as some of the solid lines would indicate, especially where the heights and temperatures of the isobaric surfaces above the Pacific Ocean are concerned when there are no upper air stations within a 100° sector of longitude.

There is much to commend in the layout and presentation which uses graded colouring as well as isopleths. The period of data used for the upper air (1957–64) has smoothed out many of the eccentricities revealed in the earlier investigation by Alt, Astopenko and others, and demonstrates the regular nature of the Antarctic atmosphere compared with that of the Arctic. One striking feature is the crescent of warm air at 100 mb in the Indian and Pacific Ocean sectors between 40°S and 50°S (Plates 2 and 3 Folio 4). North of this belt the mean tropopause heights and temperatures (Plates 5 and 6) are six months out of phase compared with the continental values. As rightly pointed out in the text, caution should be exercised in taking for granted the relative humidities at 700 mb and 500 mb. Though not stated it would appear that the relative humidities are relative to water. At the ambient temperatures experienced, 60–84 per cent is often saturation relative to ice.

The folio of surface features — Folio 8 — is more of a mixed bag, covering surface temperature (Plate 1), ranges of air temperature (Plates 2 and 3), wind roses (Plates 4–7), air temperature and wind direction (Plates 8 and 9) cyclone tracks (Plate 10), number of days with blowing snow (Plate 11) and total and mean cloud amounts (Plates 12 and 13). As in the case of the upper air data there is a lack of observations over the oceans which limits the success of Plates 2 and 3, and although the surface circulation can be inferred from the wind roses, the omission of a mean sea-level pressure map is to be regretted.

Reduction of surface temperature to potential temperature shows that east Antarctica is much colder than west Antarctica so that the cold centre is about 85°S 70°E. The cyclonic tracks across west Antarctica are partly responsible for the difference, but the implication in the text that the occasional cyclone track between the Ross and Weddell Seas is in one direction only, is open to question. It is rather irritating to find Plates 2 and 3 in degrees Fahrenheit while all other plates are in degrees Celsius.

The influence of katabatic winds is seen in both wind roses and variations of temperature with wind direction, and there is remarkably little change in pattern from one season to the next. The persistence of the westerlies in mid-latitudes is well defined. One consequence of the wind is the number of days with blowing snow, shown in histogram form in Plate 11. Unfortunately

there appears to be something wrong with the data used, and it is significant that the U.S.A. maintained stations have a much higher frequency than stations operated by other nations. From personal knowledge and experience the Halley Bay figures are an underestimate and should be of the same order of magnitude as those at McMurdo. In mitigation it must be admitted that it is difficult to obtain accurate drift-snow data from published meteorological data because significant facts can be obscured in synoptic messages.

Cloud amounts are not in histogram form but are represented by cumulative percentages of cloud less than a given amount. The curves so produced are characteristic of the station and can also be used to deduce mean cloud amounts or to form a histogram. Continental and oceanic stations prove to be very different.

Throughout both these folios the compilers have used March, June, September and December as reasonably representative, which probably accounts for the statement in the text that the continental stations could be considered to have a two-season climate. However, the normal climatological procedure using April, July, October and January would probably have been more appropriate and, as far as temperature is concerned, typifies the seasons at Halley Bay.

The brief texts of both folios are useful but would not have suffered from expansion, and I would have liked to have seen details of the nature of the data used and a bibliography of the more important literature. The only comparable atlas is the Russian *Atlas of the Antarctic* (1966) which does contain surface pressure maps and uses the usual climatological months, but does not go into the same detail of the temperature régime. Comparing the two, the Russian upper air maps appear to be less smoothed and are probably to be preferred. But taken as a whole the new folios are complementary to the Russian work, and bearing in mind the limitations and excluding Plate 11 (Folio 8) these two folios are a welcome addition to Antarctic meteorological literature and cartography.

D. W. S. LIMBERT

Air pollution, by R. S. Scorer. 130 mm × 195 mm, pp. xiii + 151, *illus.*, Pergamon Press Ltd, Headington Hill Hall, Oxford, 1968. Price: 45*s.* or flexi-cover 30*s.*

Professor Scorer is well known for his forthright views on air pollution and for his enthusiastic use of photography, and this little volume is a lively and entertaining reminder of both qualities. There are roughly 100 plates, many of them coloured, which form the basis for expounding fundamental principles and driving home practical lessons.

The general properties of airflow affecting travel of pollutants over flat country are dealt with first, and this is followed by a discussion of the rise and spread of plumes and of the way knowledge of these features can be used to estimate the dilution of a pollutant. In the next two chapters there is a discussion of the important effects of inversions, both in a high-level form and at the surface over sloping ground. Then follows a chapter on the appearance of plumes as determined by the physical nature and optical

effects of the plume constituents. Aerodynamic effects around buildings and chimneys are described in the sixth chapter. The seventh chapter discusses the various offensive aspects of air pollution and the book concludes with a chapter entitled 'Repercussions'. This underlines and reiterates the main lessons to be applied in living with air-pollution problems. In the domestic context of garden bonfires these include a recommended code of practice which no doubt many housewives will wish to have drawn to the attention of their neighbours.

As the author emphasizes, the processes of dispersion in the atmosphere are very complex. One of the features discussed at some length (in Chapter 2) is the effect of sampling time on the observed distribution of concentration downwind of a continuous source, and of the role in this connection of the wide range of eddy 'sizes'. At long distance from a source, when the plume has become wide, the bodily movement of a section of the plume is dependent on large eddies (slow variations in the wind). From this the author argues that a repeatable measurement of concentration requires a longer sampling time the longer the distance from the source. But these slow variations also affect the bodily movement of the plume at short distance and need to be included in the sampling if a reproducible value is to be obtained. Also important is the fact that as distance is increased there is a decrease in the proportion of the long-term average spread associated with crosswind bodily displacements of the plume. Consequently a short sample provides a more representative indication of average concentration at long range than it does at short range !

For meteorologists who are called upon to advise on air pollution the applicability and accuracy of diffusion formulae are vital matters. In this connection the author condemns the fallacy that pollution distribution may be calculated from some presumed universal formula, though he admits in his preface that he may seem to be overstating his case. It is undoubtedly important to deter the uncritical and uninformed use of diffusion formulae, but the useful quantitative advice which may be provided from a critical choice and use of formulae should not be forgotten or underrated.

F. PASQUILL

Environmental study, by J. B. Rigg. 220 mm × 145 mm, pp. xi+298, *illus.*, Constable and Co. Ltd, 10 Orange St., London, W.C.2, 1968. Price 45*s*.

After reading this book, few people will disagree with the author's belief in the value of environmental study in the education of our young people. The book ranges over a wide field, covering the principal aspects of our physical environment, including the sun, the atmosphere, land and sea, rocks and soils, rivers and ground water, natural vegetation, and also deals with land utilization and the urban environment.

The author maintains that environmental study is an observational science, and throughout the book there is a great emphasis on practical work. The value of class discussions is also greatly stressed, and some controversial theories are deliberately introduced in order to stimulate the exchange of ideas.

Meteorology and climatology are dealt with in some detail, with separate chapters devoted to clouds, pressure systems and air masses, meteorological instruments and records, atmospheric pollution, and the weather and the individual. There are many practical activities in this section, for example calculating the amount of water vapour in a room and the heights of clouds, the interpretation of weather maps, making a rain-gauge, drawing a field-sketch of the sky to show the weather conditions, and the collection and analysis of solid particles from the atmosphere.

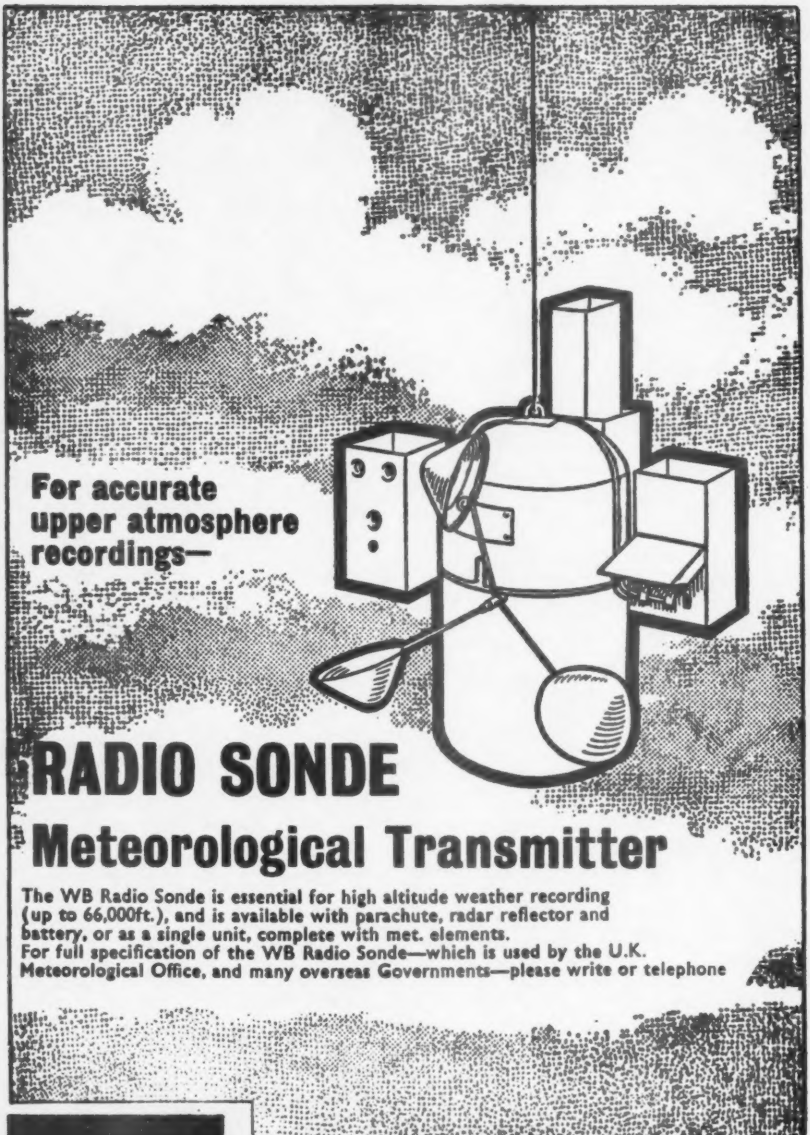
It is unfortunate that there are a number of misprints in the calculations and formulae. Another criticism, especially in view of the fact that the book comes within the high price-range, is that the publishers did not employ a studio for the drawing of the diagrams, many of which have a somewhat rough appearance.

However it should be a valuable reference book for teachers and intending teachers. As far as its use in schools is concerned, it is unlikely that a course in environmental study will be adopted for the more academically-minded pupils, who are closely involved with the G.C.E. examinations and whose curriculum is already overcrowded. The book might be used to suggest projects to A-level science students, and it could provide geographers with a series of basic experiments. In the less academic streams there should be more scope for this course, where a simpler approach could be worked out by the teacher, using the book as a guide.

F. R. DOBSON

OBITUARIES

It is with regret that we have to record the death of Mr D. K. E. Crome (X.O.) on 11 January 1969, and also that of Mr H. F. Hollands (X.O.) on 27 February 1969.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